MEASUREMENT OF PLANTAR PRESSURE WHEN WALKING WITH AND WITHOUT AN AID

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Abstract

Objective: To estimate plantar pressure when subjects walked with and without a cane at three different heights. Materials and Methods: This was an analytical cross-sectional study of 15 healthy subjects, 13 females (86.7%) and two males (13.4%). Initially, the subjects walked along a corridor approximately 10 m long while wearing a sandal with sensors on each foot. Then, they repeated the walk three times with the sandals, each time using a cane set at one of three different heights. Results: The mean pressures on C1 load cells were greater than the pressures on C5 load cells (p<0.10) when the subjects walked with a cane that was shorter than the appropriate height (p<0.10); in C6 relative to C2 when subjects walked without a cane (p<0.01), with a cane of appropriate height (p<0.05), 5 cm below the appropriate height (p<0.05) and 5 cm above the appropriate height (p<0.10); and in C7 relative to C3 when subjects walked without a cane (p<0.10). The average pressure on all cells showed differences in C2 (p<0.10), C5 (p<0.05) and C6 (p<0.01) when subjects walked without the cane, with the cane at the appropriate height, and with the cane at either 5 cm above or below the appropriate height. The mean stride time was shorter through cell signals C4T (p<0.05) and C8T (p<0.01) when the subjects walked without a cane. Conclusion: Cane height did not directly influence plantar pressure in specific regions of the subjects’ feet, nor did it influence stride time in the right or left hindfoot during walking.

Key words: cane, gait, pressure, transducers, foot.

Resumo

Objetivo: estimar as pressões plantares durante a marcha de sujeitos com e sem a utilização de uma bengala, em três alturas diferentes. Materiais e Métodos: Estudo transversal analítico constituído por 15 sujeitos hígidos, sendo 13 (86,7%) do gênero feminino e 2 (13,4%) do gênero feminino. Inicialmente, caminharam em um corredor de aproximadamente dez metros de comprimento, utilizando em cada pé uma sandála sensorizada. Em seguida, caminharam por mais três vezes com as sandálias e com uma bengala em três alturas diferentes. Resultados: As pressões médias nas células de carga C1 mostraram-se maiores do que na C5 (p<0,10) durante a marcha dos sujeitos com a bengala abaixo da altura preconizada (p<0,10), em C6 com relação a C2 durante a caminhada dos sujeitos sem a bengala (p<0.01), com a bengala na altura preconizada (p<0.05), cinco centímetros abaixo da altura preconizada (p<0.05) e cinco centímetros acima da altura preconizada (p<0.01) e em C7 com relação a C3 durante a caminhada dos sujeitos sem a bengala (p<0,10). As pressões médias de todas as células mostraram-se diferentes em C2 (p<0,10), C5 (p<0,05) e C6 (p<0,01) durante a marcha dos sujeitos sem bengala, com a bengala na altura preconizada, cinco centímetros acima e abaixo da altura preconizada. O tempo médio de uma passada foi menor através do sinal das células C4T (p<0,05) e C8T (p<0,01) durante a marcha sem bengala. Conclusão: a altura da bengala não influenciou diretamente as pressões plantares nas regiões específicas dos pés dos sujeitos, bem como o tempo da passada nos retropés direito e esquerdo, durante a marcha.

Palavras-chave: bengala, marcha, pressão, transdutores, pé.
Introduction

Walking is one of the most common human movements. It consists of motor behaviors composed of integrated body movements. The cyclical nature of walking movements allows us to establish objective criteria to distinguish between normal and abnormal movements.\textsuperscript{1,6} A normal gait depends on the satisfactory functioning of the locomotive system at all its levels. Integrity of the motor cortex and other higher brain centers, such as the cerebellum, and the proprioceptive receptors, such as golgi tendon organs and muscle spindles, is expected.

An abnormal gait has been associated with a higher risk of adverse consequences, mainly for the elderly. Such consequences include immobility, injuries, falls, reduced self-confidence, depression and dementia, which contribute to reduced functional independence and even death.\textsuperscript{2}

People with abnormal gaits often require walking aids. Devices such as canes, crutches and walkers are used by people of all ages with various walking disorders.\textsuperscript{3}

Canes are the most commonly prescribed devices; however, they are often used infrequently or inappropriately.\textsuperscript{3} They are useful for people whose joints cannot support weight due to painful symptoms, and they can increase muscular action, stabilize patients with balance deficits and reduce plantar pressure in specific regions of the feet during walking.\textsuperscript{4,5}

The distribution of pressure between the plantar regions and a supporting surface can reveal information regarding the structure and function of the foot and the postural control of the whole body. Plantar pressure analysis is of interest to many groups of professionals, such as doctors, physical therapists and engineers, and it is fundamentally associated with biomechanical analysis.\textsuperscript{6}

The rationale of the present study is based on the principle that a cane must be of an appropriate length and be supported by the hand contralateral to the affected member or by the dominant hand when the need for adjustment is not specific to one side. Few studies have investigated the effectiveness of these prescriptions.\textsuperscript{7}

Some researchers have shown that when they are not adjusted to the correct length for the user, canes can become dangerous and contribute to falls and other complications.\textsuperscript{8} These researchers believe that canes that are too low or too high can result in discomfort and increase the user's energy consumption during walking.\textsuperscript{3,7,9}

Thus, the objective of the present study was to estimate plantar pressure when subjects walked without a cane and with a cane at three different heights.

Materials and Methods

Description of the study

This was an analytical cross-sectional study conducted in the Department of Mechanics of the Guaratinguetá School of Engineering – FEG/UNESP. The inclusion criteria were men and women aged between 30 and 60 years; a weight of 80 kg or less; a shoe size of approximately 37; an absence of skeletomuscular, orthopedic, neurological and/or rheumatological diseases that could compromise walking; and the need for walking aids.

Experimental procedure

Initially, the volunteers were instructed to walk once along a corridor approximately 10 m in length while wearing previously developed sandals.

Next, the volunteers were asked to walk three more times while wearing the sandals and using an adjustable cane made by the Dilepé company.\textsuperscript{8} The cane was always supported by the subjects’ right hand, which was the dominant hand in each case.

The data for walking with the cane were collected after an approximately 10-minute-long training period with the walking aid.

After training, the subject walked the corridor once using the sandals and the cane at the appropriate height, once with the sandals and the cane set 5 cm above the appropriate height and once with the sandals and the cane set 5 cm below the appropriate height.

The most accepted method for determining the correct height for a cane is to set it equal to the distance between the greater trochanter of the patient's femur and the floor, measured when the patient is wearing walking shoes.\textsuperscript{10} The length of the greater trochanter of the femur was defined as the vertical distance from the most prominent part of the greater trochanter to the ground.\textsuperscript{11} The patient should have an elbow flexion of 15 to 30\textdegree while the cane is in contact with the ground.\textsuperscript{10}

The sandals and the cane were connected to a Model 8 Spider\textsuperscript{8} (HBM) tension amplifier system. This system amplified and sent the signals obtained during collection to a microcomputer, where they were acquired, stored and manipulated using Catman Easy\textsuperscript{8} software.

A sampling frequency of 100 Hz was used, and the mean of acquisition was 25 seconds. The mean sensitivity of the sensors was 1812.3 MPa/(mV/V).

Each volunteer walked once along a 10-m corridor, first without the cane and then with the cane set at three different heights.
Two of the eight load cells shown in Figure 1 are found in the right and left forefoot, one in the right and left middle foot and one in the right and left hindfoot.

![Figure 1 – The distribution of load cells in the right foot (C1 to C4) and left foot (C5 to C8).](image)

Throughout all of the walks (with and without the cane), six peaks of plantar pressure were used for each load cell (C1 to C8). The mean pressure was obtained from these six peaks. Moreover, for load cells C4 and C8, which are located in the right and left hindfoot, stride times were analyzed for two of the walks, and the mean of those two times was determined. After the data were collected, they were compared and analyzed statistically.

**Statistical analysis**

The non-parametric Mann-Whitney U-test and Friedman’s test were used for the statistical analysis of data because they are appropriate for small samples. The Kolmogorov-Smirnov test was used to identify whether the data had a normal distribution. The significance level adopted in this study was α=10% (p < .10).

The data were presented in descriptive form for medians and in tables showing the mean values of the ranks for the load cells, the cane heights (normal, high, low and not present) and the respective p-values. The dependent variable of this study was mean plantar pressure, and the independent variables were the different cane heights (normal, high and low).

**Results**

Fifteen healthy subjects participated in the study: 13 (86.6%) were female and two (13.4%) were male. In terms of anthropometric variables, the subjects were between 25 and 51 years of age (median=47), with a weight between 46 kg and 69.7 kg (median=64.5) and a height between 1.47 m and 1.67 m (median=1.56).

Table 1 shows the mean values of the ranks of the mean plantar pressure of all load cells while the subjects walked without the cane and with the cane at normal, low and high settings.

**Table 1** – The mean values of the ranks of mean pressures (MEAN) in load cell pairs C1-C5, C2-C6, C3-C7 and C4-C8 of subjects walking without a cane (WC) and with the cane at normal (NC), low (LC) and high (HC) height values.

<table>
<thead>
<tr>
<th></th>
<th>WC MEAN (15)</th>
<th>NC MEAN (15)</th>
<th>LC MEAN (11)</th>
<th>HC MEAN (15)</th>
</tr>
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<tbody>
<tr>
<td>C1</td>
<td>15.1</td>
<td>17.9</td>
<td>13.8</td>
<td>17.7</td>
</tr>
<tr>
<td>C5</td>
<td>15.9</td>
<td>13.1</td>
<td>9.1</td>
<td>13.3</td>
</tr>
<tr>
<td>C2</td>
<td>11.1</td>
<td>12.1</td>
<td>8.4</td>
<td>12.4</td>
</tr>
<tr>
<td>C6</td>
<td>19.9***</td>
<td>18.9**</td>
<td>14.6**</td>
<td>17.8*</td>
</tr>
<tr>
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<td>12.8</td>
<td>16.5</td>
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</tr>
<tr>
<td>C7</td>
<td>18.2*</td>
<td>14.5</td>
<td>11.4</td>
<td>15.2</td>
</tr>
<tr>
<td>C4</td>
<td>15.7</td>
<td>14.3</td>
<td>10.5</td>
<td>14.0</td>
</tr>
<tr>
<td>C8</td>
<td>16.7</td>
<td>12.4</td>
<td>17.0</td>
<td></td>
</tr>
</tbody>
</table>

*p < .10; **p < .05; ***p < .01 obtained with the Mann-Whitney test.

The computational program SPSS® Version 17.0 was used for this study.

**Ethical Considerations**

This study was submitted to and approved by the Committee of Ethics in Research of the Pindamonhangaba School – CEP/FAPI under Protocol Number 139/2010.
A statistically significant difference was observed between the mean values of the mean pressures for load cell C1 (the head of the first right metatarsal) compared with the values for cell C5 (the head of the first left metatarsal) when subjects walked with the cane set below the appropriate height (p < .10).

The mean pressures in cell C6 (the head of the fifth left metatarsal) were also different than the mean pressures in the C2 cell (the head of the fifth right metatarsal) when the subjects walked without the cane (p < .01) and with the cane at the appropriate height (p < .05), below the appropriate height (p < .05) and above the appropriate height (p < .10).

The same result was observed in cell C8T (p < .01). The same result was observed in cell C8T (p < .01). The same result was observed in cell C8T (p < .01). The same result was observed in cell C8T (p < .01). The same result was observed in cell C8T (p < .01).

Discussion

The gait of an individual who uses a cane normally involves planting the cane on the side opposite the most severely affected limb, such that the cane is advanced with the impaired limb during walking.12 Because the subjects in the present study did not present any pathology in the lower limbs, each subject held the cane in his/her dominant (right) hand throughout the experiment. The comparisons performed between the C1 and C5 load cells showed that the mean pressures were greater on load cell C1 (the head of the first right metatarsal) than on load cell C5 (the head of the first left metatarsal) when subjects walked with the cane set above the appropriate height (p < .10).

There was also a significant difference in load cell C7 (left middle foot) relative to cell C3 (right midfoot) when the subjects walked without the cane (p < .10).

No statistically significant difference was observed in cells C4 and C8 when the subjects walked without the cane or when they walked with the cane at the three different heights (NS).

Table 2 shows the mean values of the ranks of the mean pressures in all load cells when the subjects walked without the cane and with the cane at the appropriate height and above and below the appropriate height, as well as the mean values for stride time in cells C4 and C8.

<table>
<thead>
<tr>
<th>N = 11</th>
<th>WC MEAN</th>
<th>NC MEAN</th>
<th>HC MEAN</th>
<th>LC MEAN</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>2.3</td>
<td>3.1</td>
<td>2.2</td>
<td>2.5</td>
<td>.34</td>
</tr>
<tr>
<td>C2</td>
<td>3.3</td>
<td>1.9</td>
<td>2.4</td>
<td>2.5</td>
<td>.09</td>
</tr>
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<td>2.9</td>
<td>2.3</td>
<td>2.6</td>
<td>.52</td>
</tr>
<tr>
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<td>2.7</td>
<td>2.4</td>
<td>2.3</td>
<td>2.6</td>
<td>.86</td>
</tr>
<tr>
<td>C5</td>
<td>3.5</td>
<td>2.2</td>
<td>2.3</td>
<td>2.0</td>
<td>.02</td>
</tr>
<tr>
<td>C6</td>
<td>3.7</td>
<td>2.2</td>
<td>1.8</td>
<td>2.3</td>
<td>.002</td>
</tr>
<tr>
<td>C7</td>
<td>3.2</td>
<td>2.4</td>
<td>1.9</td>
<td>2.5</td>
<td>.14</td>
</tr>
<tr>
<td>C8</td>
<td>2.8</td>
<td>2.1</td>
<td>2.5</td>
<td>2.5</td>
<td>.61</td>
</tr>
<tr>
<td>C4T</td>
<td>1.6</td>
<td>3.0</td>
<td>2.8</td>
<td>2.6</td>
<td>.03</td>
</tr>
<tr>
<td>C8T</td>
<td>1.1</td>
<td>3.3</td>
<td>3.0</td>
<td>2.7</td>
<td>.001</td>
</tr>
</tbody>
</table>

p-values obtained using the Friedman test.

The mean pressure values were significantly different in cells C2 (p < .10), C5 (p < .05) and C6 (p < .01) when the subjects walked without the cane, with the cane at the appropriate height and with the cane set above and below the appropriate height.

By contrast, the mean pressures in cells C1, C3, C4, C7 and C8 were not significantly different during walking without the cane and with the cane at the three different heights (NS).

The mean stride time in cell C4T was significantly different (p < .05) during the walks. The same result was observed in cell C8T (p < .01).

Discussion

The gait of an individual who uses a cane normally involves planting the cane on the side opposite the most severely affected limb, such that the cane is advanced with the impaired limb during walking.12 Because the subjects in the
C2 (the head of the fifth right metatarsal) when subjects walked without the cane (p < .01) and with the cane at the appropriate height (p < .05), below the appropriate height (p < .05) and above the appropriate height (p < .10). These results agree with the studies of Wertsch et al., who analyzed the effect of using a cane in the ipsilateral versus contralateral hands of nine subjects with no known illnesses or injuries that could affect walking and who were attempting to take pressure off the foot. Plantar pressure was measured in seven specific regions of each foot using a system of portable soles with sensors. The authors found that the load on the foot contralateral to the cane increased by 35%, especially in the lateral region. This led to the conclusion that there is probably a greater predisposition toward the development of ulcerations in the head of the fifth metatarsal contralateral to the cane.13

The mean pressures on load cell C7 (left midfoot) were greater than on cell C3 (right midfoot) when the subjects walked without the cane (p < .10). This does not support Wertsch et al.’s studies, in which a load reduction was reported on the plantar surface contralateral to the cane compared with walking without a cane.13

Regarding the values of the mean pressures of all load cells, cell C2 (the head of the fifth right metatarsal) showed a possible increase in mean pressure during walking without a cane compared with walking using the cane at the appropriate height (p < .10), whereas cell C5 (the head of the first left metatarsal) showed increased mean pressures during walking without the cane compared with walking with the cane below the appropriate height (p < .05). In cell C6 (the head of the fifth left metatarsal), an increase in mean pressures was found during walking without the cane compared with walking with the cane set higher than the appropriate height (p < .01). These results show that greater mean pressure values were measured on load cells C2, C5 and C6 when the subjects walked without the cane, and lower values were measured when the subjects walked with the cane set at appropriate, low and high height values. This partially agrees with the studies of Kwon and Mueller, who showed that a cane can be used as an auxiliary device during walking to reduce plantar pressure in specific regions of the foot, such as the forefoot contralateral to the cane; furthermore, cane use can increase the load on the ipsilateral forefoot, mainly in the region of the head of the first metatarsal.5

Comparing these findings with those of the present study, the cells that represented the left forefoot contralateral to the cane, C5 and C6, showed lower pressure values during walking with the cane at low and high height values, respectively, relative to walking without the cane. The cell that represented the lateral region of the right forefoot ipsilateral to the cane, C2, also showed a possible reduction in pressure values when the cane was set at the appropriate height as opposed to walking without the cane. This may have occurred because overloads are more commonly observed at the head of the first metatarsal in the foot ipsilateral to the cane, which may have contributed to a reduced overload at the head of the fifth metatarsal.

According to Bateni and Maki, reduction in loads of the lower members is an important benefit of the cane for patients with muscular weakness, injury or pains in the lower members. However, from their studies, Kwon and Mueller concluded that although the cane is capable of alleviating overloads in the contralateral foot, it increases overload in the ipsilateral foot.14,5

With regard to the mean stride time in cell C4T, a statistically significant difference (p < .05) was observed during the walks. The same result was observed in cell C8T (p < .01). The mean stride time was lower during walking without the cane and higher when walking with the cane at the appropriate height; that is, gait speed was faster without the cane and slower with the cane. This finding is consistent with the studies of Bateni and Maki, who verified that cane use during walking increases oxygen consumption by up to 33%, leading to a reduction in speed.14 By contrast, another study by Foley et al. involving 10 healthy elderly subjects found that cane use did not modify the subjects’ oxygen consumption or heart rates, although the authors did report a reduction in walking speed.15

Jones et al. evaluated the energy consumption of 30 patients with osteoarthrosis of the knee when walking with and without a cane set at three different heights. The authors concluded that walking speed diminished with cane use and that there was an increase in energy consumption during walking with a cane.16 In contrast, Mullins and Dent suggested that the height of the cane does not modify energy consumption during walking, although their studies were performed with healthy subjects, which might have been a limitation.17

The mean stride times during walking without the cane in the present study were approximately 1.6 m/s (C4T) and 1.1 m/s (C8T), which approached the values considered normal. According to Perry, the mean cadence of men between 18 and 64 years of age is 111 steps per minute, with a mean speed of 1.43 m/s; for Kadaba et al., the mean cadence is 112 steps per minute, with a mean speed of 1.34 m/s.18,19 However, the average stride speed while walking with the cane at the three different heights was slower in the present study, possibly due to the energy expended in supporting the device when walking.

An important observation is that the present study did not measure the loads applied to the upper limb. Various studies have measured the load...
placed on a cane when it is used for walking. Most studies found that cane users rarely transfer more than 15 to 20% of their body weight onto the device, although the load on the cane often depends on the nature of the individual's instability.20

Anglin et al. used a biomechanical model on six healthy adults aged between 51 and 64 years to estimate the muscular force acting on the shoulder and found that the force of contact of the glenohumeral joint can be three times greater than the body weight when walking with a cane.21 According to Bachschmidt et al., kinematic data indicate that the elbow is typically flexed and the fist extended when a cane is used, suggesting significant demand on the extensor muscles of the elbow and the flexors of the fist.22

Few studies, however, have directly measured muscular activity during walking with a cane, although one study found that muscular activation levels could be reduced if the cane handle's design was modified.23

The possible limitations of this study were the low sample number, the low number of load cells used to measure plantar pressure, the heterogeneity of the subjects' heights and the fact that the subjects did not present with infirmities of the lower limbs. It was thus possible to estimate the plantar pressure when the subjects walked without a cane and with a cane set at three different heights. Our results allowed us to conclude that the cane's height did not directly influence plantar pressure in specific regions of the subjects' feet or stride time in the right and left hindfoot during walking.

References


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